The laser surface treatment of polycrystalline diamond wafers

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The ultraviolet laser was applied for the polycrystalline diamond (PCD) wafers fabricated by physical vapor deposition (PVD) to improve the machinability of PCD wafer in this work. Laser surface treatment experiments with line scanning mode were conducted to investigate the microgroove morphology. The influence of laser scanning velocity on the microgroove morphology was studied. The width and depth of microgroove decreased with the increasing of laser scanning velocity. The ratio of width and depth increased with laser scanning velocity. The laser oscillation technology was used to modify the microgroove morphology. The laser oscillation increased the width and depth of the microgroove. Besides, the laser oscillation weakened the influence of laser scanning velocity on the ratio of width and depth. Finally, laser surface treatment experiment with areal scanning mode was conducted. The surface roughness of laser-treated surface decreased compared to the base material surface.

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1. Introduction

As the 4th semiconductor, Polycrystalline diamond (PCD) has large bandgap width, high electron mobility, high thermal conductivity and low thermal expansion coefficient to meet the performance required for semiconductor devices, such as low energy loss, high voltage resistance, high temperature resistance, high-speed operation and miniaturization[1].

However, the ultra-precision machining for the flattening of PCD wafer fabricated by physical vapor deposition is a difficult problem. Due to the high hardness and high brittleness, the PCD wafers are highly susceptible to cracking during the ultra-precision machining. The cracking has become the key issue hindering the mass production of PCD wafers[2].

In recent years, studies have been conducted to applied laser to machine the surface of brittle and hard materials[3-5]. Hualu Wang et al. [6] found that the diamond was converted to amorphous carbon and graphite after laser irradiation. The thermal stress in the groove introduced by picosecond laser is larger than that created by nanosecond laser. Q wu et al. [7] found that the surface roughness of diamond tools was improved by nanosecond laser. The increase of pulse repetition and shot number could improve surface quality. Maxim Komlenok et al. investigated the effect of the laser incident angle, number of passes, scanning speed and laser fluence on the surface roughness. The initial roughness was reduced from 5 μm to 1 μm by femtosecond laser. Tianye Jin et al. [8] developed a strategy of normal-irradiated trochoidal femtosecond laser machining (NTFM) to process the PCD. The material removal rate of NTFM was almost twice as high as the conventional non-trochoidal femtosecond laser milling. Taras V. Kononenko et al. [9] deposited different kinds of coatings (titanium, graphite) on the diamond surface to avoid the laser-induced subsurface damage. V.N. Tokarev et al. [10] established a theoretical model for the interaction of excimer laser radiation with rough polycrystalline diamond films to study the influence of laser incident angle, irradiation intensity and number of laser pulses.

In the present work, the laser treatment of PCD surface was conducted with two line scanning modes. The microgroove fabricated by laser ablation was studied. The influence of laser scanning velocity on the microgroove size was investigated. Finally, the PCD surface was ablated by the laser areal scanning mode.

2. Experimental setup

The polycrystalline diamond (PCD) samples used in this study were fabricated by Chongqing Origin Stone Element Science and Technology Development Co., Ltd. The samples were manufactured by physical vapor deposition. The diamond grew from the Si substrate surface. The size of each sample was 8 mm × 8 mm × 1 mm. The thickness of PCD layer on the Si substrate was 300 um - 500 μm. The surface morphology was observed by Alicona IFM G4. Fig.1 showed the microstructure and morphology of PCD layer surface. As shown in Fig.1a, the PCD layer was composed of many individual diamond particles. The size of the particles was about 200 μm. The particles stacked together. Therefore, the surface of PCD layer was uneven and irregular.

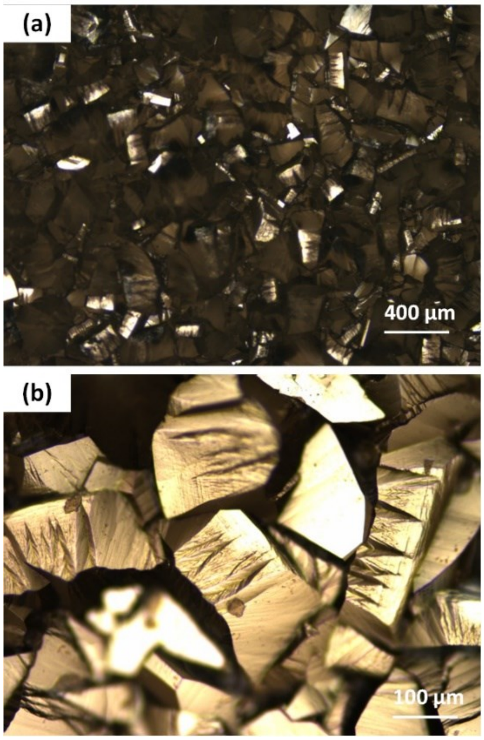

Fig. 1 The microstructure and morphology of original surface

The ultraviolet laser was applied in this study due to its high absorption rate by diamond. The laser parameters used in the laser treatment experiment were listed as following: the pulse width was 15ns, the repetition frequency was 60 KHz, the wavelength was 355 nm. The wavelength was 355 nm. Laser line scanning on the PCD layer surface was conducted to characterize the microgroove morphology caused by laser. Besides, laser oscillation technology was also applied in laser line scanning to study the effect of laser oscillation on microgroove morphology. Finally, laser areal scanning on the PCD layer surface was conducted.

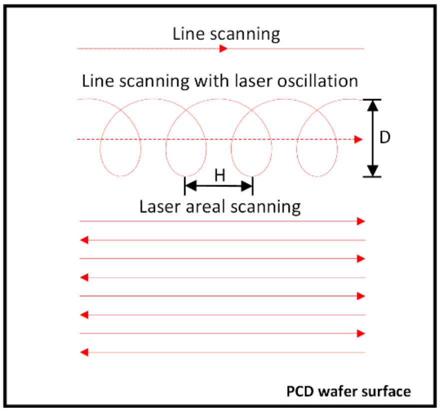

Fig.2 The laser scanning mode in laser treatment experiments

The experiment parameters were listed in Table.1 and Table.2, respectively. In the laser line scanning experiment, the effect of laser scanning velocity on the microgroove morphology was studied. The laser scanning velocity ranged from 20 mm/s to 100 mm/s. In the laser line scanning experiment with laser oscillation, the laser oscillation diameter D was set as 20 μm. The oscillation distance H was set as 10 μm. In the laser areal scanning experiment, the hatch distance was set as 15 um. Different laser scanning velocity (20 mm/s, 40 mm/s, 60 mm/s, 100 mm/s and 200 mm/s) was applied in the laser areal scanning experiments.

Table.1 The process parameters for laser line scanning experiments

No.	Laser power (W)	Laser scanning velocity (mm/s)
A1	15	20
A2		40
A3		60
A4		80
A5		100

Table.2 The process parameters for laser areal scanning experiments

No.	Laser power (W)	Laser scanning velocity (mm/s)	D (μm)	H (μm)
B1	15	20	20	10
B2		40		
B3		60		
B4		80		
B5		100		

3. Results and discussions

Fig.3 showed the microgrooves caused by laser treatment on the PCD layer surface with different laser scanning velocities. It was obeserved that the width of microgroove varied little with the increasing of laser scanning velocity. However, the depth of microgroove decreased with the increasing of laser scanning velocity. Beside, when the laser scanning velocity was 20 mm/s or 40 mm/s, the width of microgroove varied little along laser scanning direction. When the laser scanning velocity was greater than 40 mm/s, the width of microgroove varied apparently along laser scanning direction. This phenomenon was caused by 2 factors : (1) The absorb laser energy in unit area irradiated by the laser decreased to the critical value that caused phase transition of diamond when laser scanning velocity were larger than 40 mm/s. (2) The height of the surface fluctuated greatly as shown in Fig.1b.

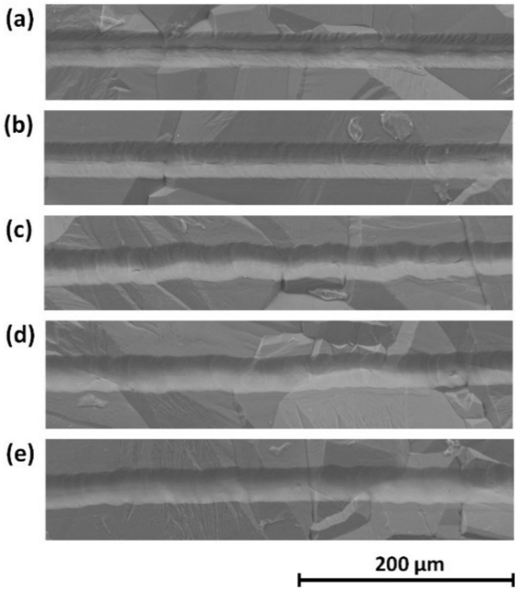

Fig.3 The microgrooves caused by laser treatment on the PCD layer

surface with laser scanning velocity of: (a) 20 mm/s; (b) 40 mm/s; (c) 60 mm/s; (d) 80 mm/s; (e) 100 mm/s

Fig.4 showed the cross-sectional morphologies of the microgrooves with different laser scanning velocites. It was found that when the laser scanning velocity was 20 mm/s, the depth of microgroove was the greatest. With the increase of laser scanning velocity, the depth of microgroove decreased apparently.

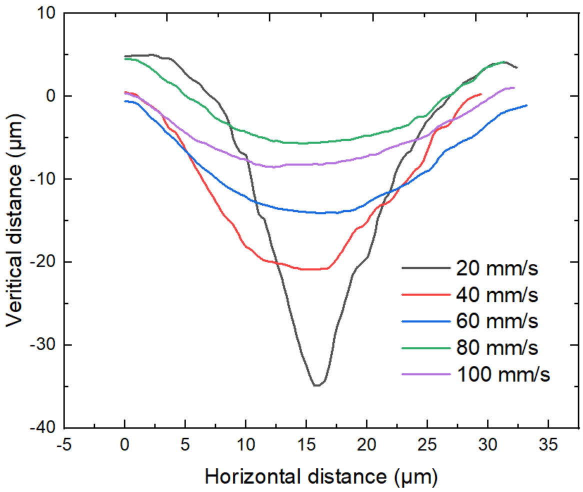

Fig.4 Cross-sectional morphologies of microgrooves for line scanning

Table.3 listed the width and depth of the microgrooves with different laser scanning velocities. It was found all the width was around 30 μm. It was speculated that phase transition occurred once the area was irradiated by laser. In this circumstance, the width of microgroove varied little. However, the depth of microgrooves ranged from 9.2 μm to 39.1 um. Therefore, the ratio of width and depth could be adjusted by laser scanning velocity, which meant that the microgroove morphology could be controlled by laser scanning velocity.

Table.3 The widths and depths of microgrooves for line scanning

Laser scanning velocity (mm/s)	Width (μm)	Depth (μm)
20	32.4	39.1
40	29.4	21.3
60	33.4	13.2
80	31.3	10.0
100	32.1	9.2

Fig.5 showed the microgrooves caused by laser treatment on the PCD layer surface with laser oscillation. Compared with the microgrooves without laser oscillation, the width and depth of microgrooves increased apparently. With laser oscillation, there were laser oscillation paths on both side wall of the microgroove. Besides, when the laser scanning velocity was 20 mm/s or 40 mm/s, an obvious platform was formed at the bottom of microgrooves.

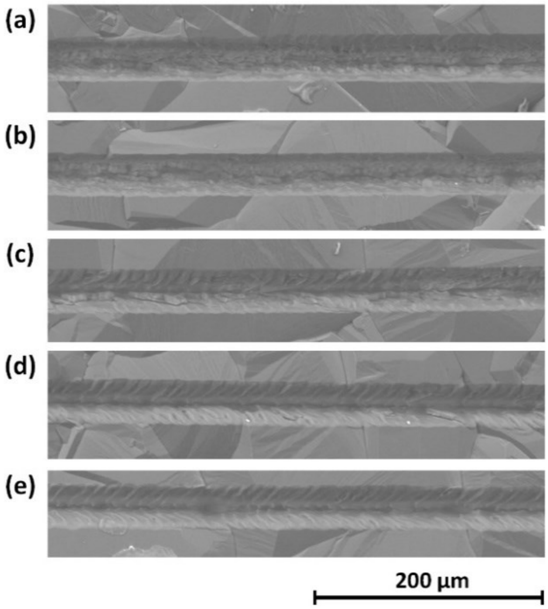

Fig.5 The microgrooves caused by laser treatment on the PCD layer surface with laser scanning velocity of: (a) 20 mm/s; (b) 40 mm/s; (c) 60 mm/s; (d) 80 mm/s; (e) 100 mm/s with laser oscillation

Fig.6 showed the cross-sectional morphologies of the microgrooves with laser oscillation. It was found that all the microgrooves had a platform at the bottom. Besides, the width of the platform decreased with the increase of laser scanning velocity. With laser oscillation, the depth of microgroove increased apparently.

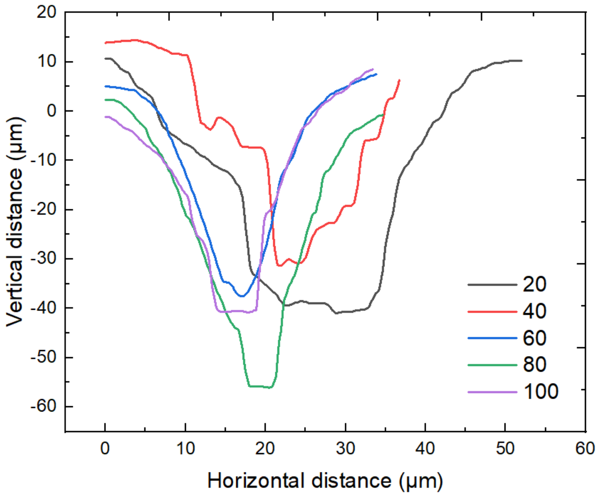

Fig.6 Cross-sectional morphologies of microgrooves for line scanning

Table.4 listed the width and depth of the microgrooves with laser oscillation. It was found that only when the laser scanning velocity was 20 mm/s, the width of microgroove increased from 32.4 μm to 52.0 um. The increment of microgroove width was equal to the laser oscillation diameter (20 μm). This indicated that there was a critical value for laser scanning velocity between 20 mm/s and 40 mm/s. When the laser scanning velocity was greater than that critical value, The absorb laser energy in unit area irradiated by the laser was not sufficient to cause phase transition. The width of microgroove ranged form 43.8 μm to 51.4 μm, which was apparently greater than that without laser oscillation. Therefore, the laser oscillation promoted the increase of microgroove depth.

Table.4 The widths and depths of microgrooves for line scanning

Laser scanning velocity (mm/s)	Width (μm)	Depth (μm)
20	52.0	51.4
40	36.1	50.0
60	33.8	43.8
80	34.7	59.0
100	33.6	44.5

Fig.7 showed the macrostructures of areal laser-treated PCD layer surface with different laser scanning velocities. It was found that all the laser-treated area was ablated. The surface of laser-treated area was covered by a black phase. The ablation degree decreased with the increase of laser scanning velocity.

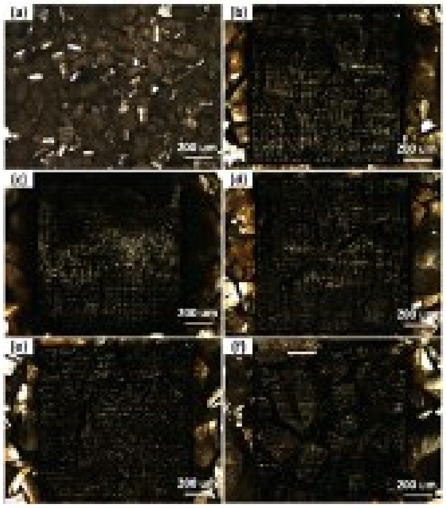

Fig.7 The macrostructures of areal laser-treated PCD layer surface: (a) base material; (b) 20 mm/s; (c) 40 mm/s; (d) 60 mm/s; (e) 100 mm/s; (f) 200 mm/s

Fig.8 showed the surface roughness Sa of areal laser-treated PCD layer surface. The Sa of base material was 6.1 μm. It was found that the Sa of laser-treated area decreased to 4.0 μm when the laser scanning velocity was 100 mm/s. It demonstrated that the PCD layer surface could be flatten by laser treatment.

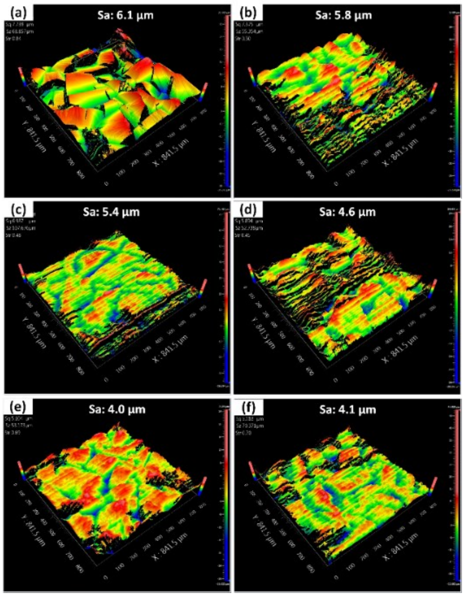

Fig.8 The surface roughness of areal laser-treated PCD layer surface

4 Conclusion

In present study, laser treatment on PCD wafer surface was applied to decrease the surface hardness. Laser line scanning and laser real scanning experiments were conducted. The microgroove depth decrease with the increase of laser scanning velocity. The laser oscillation apparently increased the microgroove depth. After laser treatment, sapphire was formed on the laser-treated surface. The surface roughness decreased after laser treatment.

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REFERENCES

[1] B.R. Huang, S.J. Chang, The electrical conduction mechanism for the polycrystalline diamond membrane in the voltage range of +/- 50 V, Mater Lett, 56 (2002) 867-872.

[2] S. Shikata, Potential and Challenges of Diamond Wafer Toward Power Electronics, Int J Auto Tech-Jpn, 12 (2018) 175-178.

[3] Z.Q. Li, J. Wang, Q. Wu, Ultrashort Pulsed Laser Micromachining of Polycrystalline Diamond, Ultra-Precision Machining Technologies, 497 (2012) 220-224.

[4] Q. Wu, J. Wang, An Experimental Investigation of the Laser Milling Process for Polycrystalline Diamonds, Materials Processing Technology, Pts 1-4, 291-294 (2011) 810-815.

[5] M.D. Perry, B.C. Stuart, P.S. Banks, M.D. Feit, V. Yanovsky, A.M. Rubenchik, Ultrashort-pulse laser machining of dielectric materials, J Appl Phys, 85 (1999) 6803-6810.

[6] H.L. Wang, Q.L. Wen, X.P. Xu, J. Lu, F. Jiang, C.C. Cui, Ablation characteristics and material removal mechanisms of a single-crystal diamond processed by nanosecond or picosecond lasers, Opt Express, 29 (2021) 22714-22731.

[7] Q. Wu, J. Wang, Development in Laser Polishing of Polycrystalline Diamond Tools, Surface Finishing Technology and Surface Engineering Ii, 135 (2010) 1-6.

[8] T.Y. Jin, D.H. Liu, J.Y. Chen, T. Zhao, C.Y. Zhang, Precise and efficient surface flattening of polycrystalline diamond by normal-irradiated trochoidal femtosecond laser machining, J Manuf Process, 74 (2022) 456-464.

[9] T.V. Kononenko, P.A. Pivovarov, A.A. Khomich, R.A. Khmelnitsky, V.G. Plotnichenko, V.I. Konov, Processing of polycrystalline diamond surface by IR laser pulses without interior damage, Opt Laser Technol, 117 (2019) 87-93.

[10] V.N. Tokarev, J.I.B. Wilson, M.G. Jubber, P. John, D.K. Milne, Modeling of Self-Limiting Laser-Ablation of Rough Surfaces - Application to the Polishing of Diamond Films, Diam Relat Mater, 4 (1995) 169-176.